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EVALUATION OF SEEPAGE LOSSES IN AN EARTH LINED CANAL: A CASE STUDY OF UNIVERSITY OF UYO FARM, UYO, NIGERIA.

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KEYWORDS: Hydraulic Conductivity, Moisture Content, Seepage, Earth lined Canal, Ponding, Bentonite.

ABSTRACT

The research farm of the department of Agricultural Engineering, University of Uyo was the study area. The purpose of the study was to evaluate seepage losses in an earth lined canal. The research was carried out on two different canals located at about 30m apart. A prior analysis of some properties of the liners and soil sample from the canal was carried out in the soil mechanics laboratory of the University. These include: particle size distribution and soil texture, soil classification, moisture content, soil hydraulic conductivity and Atterberg''s limits. Experiment on the seepage losses was conducted on a 5m long, 1m width and 1m deep canals, with only 0.6m depth of canal lined with mixture of 7 headpands (175kg) of clay and 2kg of bentonite. Water was filled to only 0.6m out of the 1m depth of the canal. Ponding method was used to measure the volume of water lost through seepage taking account of losses due to evaporation while other losses from discharge devices were not accounted for. Average seepage losses of 0.29m^3/hour and 0.05m^3/hour were obtained for the unlined and lined canals respectively. The study recommends that the mixture of clay and bentonite in the proportion stated be used by small and medium scale farmers who wish to control seepage losses with a moisture saving capacity of 82.8% within study area.

I. INTRODUCTION

The conservation of water is becoming increasingly important as the demand for this vital natural resource continues to rise rapidly and new sources of supply are becoming scarce. Thus, there are growing concerns over water losses in agricultural systems and studies concerning the conservation of this natural resource with its wide application become eventful. Seepage from open channels is one of the major problems involved in the design of irrigation networks. However the advantage of conserving water is necessary as water is becoming a scarce commodity.

The conservation of irrigation water is often of primary importance to the agriculture development of a country. The reduction or elimination of seepage losses in irrigation canals by means of linings assures better utilization of the conveyed water and an improved economic situation. Seepage losses from earthen irrigation channels depend on a number of factors and vary from (30 to 50) percent of the discharge available at the head of an irrigation system. In addition, the seepage losses can be estimated about (3-8) ℓ/s per (100) m for unlined canal carrying (20-60) ℓ/s (Smout,2007; Abu-Gulul, 1975).

Seepage in irrigated agriculture has been defined as the movement of water in or out of earthen irrigation canals through pores in the bed and bank material. There are many factors that affect seepage from canals (Worstell 1976): texture of the soil in the canal bed and banks, water temperature changes, siltation conditions, bank storage changes, soil chemicals, water velocity, microbiological activity, irrigation of adjacent fields, evaporation, evapotranspiration and water table fluctuations. Proper design and construction of conveyance systems are necessary to minimize seepage, due to the limited available water supply and ever increasing demand for water. Seepage is not only a waste of water, but it may also lead to other problems such as water logging and salinization of agricultural land (Iqbal et al., 2002).

Losses in permeable sandy soils may be as much as ten times that in tight soils and in heavy clay soils, it may be negligibly low. By lining the canal, the velocity of the flow can increase because of the smooth canal surface. For

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example, with the same canal bed slope and with the same canal size, the flow velocity in a lined canal is 1.5 to 2 times that in an unlined canal, which means that the canal cross- section in the lined canal be smaller to deliver the same discharge, Karaatz (2007). Other possible benefits of lining according to Karaatz (2007) are that water will be conserved, seepage of water into adjacent land or roads will be minimized, canal dimensions will be reduced and maintenance will also be reduced (Abu-Gulul, 1975; Al-Husseini, 2009).

Canals continue to be major conveyance systems for delivering water for irrigation. The seepage loss from irrigation canals constitutes a substantial percentage of the usable water. The loss of water by seepage from unlined canals generally varies from 0.3 to 7.0 m^3/s per $10^6 m^2$ of wetted surface (Swamee et al., 2001). Moreover, although the lining of canals is expensive, the cheap un-lined earth canals have problems associated with its usage which hamper its efficiency. It therefore becomes relevant and important to investigate the seepage of water using readily available and less costly earth canal lining materials within the reach of the farmer for effective and efficient water delivery for irrigation.

The main purpose of this study is to evaluate the seepage through an earth-lined canal in order to recommend the lining material for canal lining in a selected area in Akwa Ibom State. However, the specific objectives are: (1) To design and construct earth canals for irrigation. (2) To line the canals with readily available clay earth materials and some quantities of bentonite (3) To measure the seepage loss in the lined canal. (4) To recommend or not the lining material for earth canals of related soil type.

Formulation of the problem

The seepage in an irrigation canal refers to the water that percolates into the soil strata through the wetted perimeter of a canal (Rushton and Redshaw 1979). Seepage losses affect the operation and maintenance of the canals in the sense that part of the water diverted for the users is lost from the conveyance system, and at the same time this water might produce piping, erode the bank of the canals whether they are lined or not, produce excessive saturation, uplift pressure, which might produce failures of the canal and other structures (Rushton and Redshaw 1979). For instance, some canals are lined in order to reduce the seepage loss; however, according to British researchers the seepage losses in a concrete lined canal might be the same as an unlined canal if 0.01% of the lined area consists of cracks (Merkley 2007).

The seepage loss from canals is governed by hydraulic conductivity of the subsoil, canal geometry, hydraulic gradient between the canal and the aquifer underneath, and initial and boundary conditions. The seepage loss from a canal in an unconfined flow condition is finite and maximum when the water table lies at a very high depth.

The seepage loss from a canal in a homogeneous and isotropic porous medium, when the water table is at a very large depth, according to Swamee (1994), can be expressed as

$$q_s = KyF \qquad .1$$

Where q_s is the seepage discharge per unit length of canal (m^2/s);

k is hydraulic conductivity of the porous medium (m/s);

y is the depth of water in the canal (m);

F is the function of channel geometry (dimensionless); and

yF is the width of seepage flow at the infinity.

Hereafter, F will be referred to as the seepage function.

Canals continue to be major conveyance systems for delivering water for irrigation, but the seepage loss from irrigation canals constitutes a substantial percentage of the usable water. By the time the water reaches the field, it has been estimated that the seepage losses are of the order of 45% of the water supplied at the head of the canal. According to the Indian Standard Measurement (1980), the loss of water by seepage from unlined canals in India generally varies from 0.3 to 7.0 m^3/s per 10 6 m^2 of wetted surface. The transit losses are more accentuated in alluvial canals. It has been estimated that if the seepage loss is prevented, about 6,000,000 ha of additional area could be irrigated. The seepage loss results not only in depleted freshwater resources but also cause water logging, salinization, and ground-water contamination.

Seepage losses differ widely because of the varied nature of canal locations and surrounding conditions. The topography, soils, ground water, and conveyance material of any given area vary greatly both individually and in

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their total effect. The factors which affect seepage are described based on howthey affect the component of Darcy's seepage equation. According to Netz (1980), they are as discussed below.

Seepage is theoretically backed up by Darcy's theory (Christopher, 1981; Sonnichsen, 1993). This can be expressed by the equation 2

below:

$$Q = K_e HA. \quad \ldots\ldots..2$$

Where Q is the seepage rate in m^3/day

k_e is the effective hydraulic conductivity in and under the canal bed in m/day

H is the hydraulic gradient in m/m, and A is the cross-sectional area of the seepage flow in m^3

Though no quantitative assessment of seepage from the branch canal has been made by way of any observation / collection of data, there is however, a general perception that some percentage of the flow is lost by way of seepage. An overview of the command adjacent to the branch canals also indicates land degradation and salinization in considerably large areas which is reflective of shallow ground water table conditions, contributed by seepage from the branch canals apart from other causes. Seepage losses from branch canal infiltrate into the ground water contributing to water logging and salinity.

Ponding loss measurement method

This is the most dependable and reliable method for measuring the quantity of water loss through seepage from the existing canals in a particular reach is by the ponding method. It consists of constructions of a temporary water tight dyke of bulk head across the canal. The canal above the dyke is filled with water to a certain measured level. After allowing the water to stand for some time, the level of water in the canal is recorded. Any drop in the level is obviously due to seepage through the section of canal. The canal is then added sufficient quantity of water to maintain its original level. This volume of water, which is measured accurately, is equal to the total seepage loss during the particular time interval. The volume of water divided by the time determines the rate of seepage loss through the canal (Sarki et al, 2008). However, the demerit of this method though is measurements of test reach, evaporation and rainfall, and effect of wind action causing waves.

Inflow–out flow loss measurement

This method involves measuring the amount of water flows into a channel at inlet of the section and amount which flows out at the tail of the section when no water is being usefully directed between the two measuring points. The loss is the difference between these two measured points. The measurement can be either of total volumes of water or if the channel is flowing steadily with its little change in the measured flow rate at either end directly of flow rates (Sarki et al, 2008).

The flow is monitored in both devices until the steady flow is obtained. The flow measurement device will generally change the depth of flow and channel storage upstream from the device, therefore five minutes to an hour may be required depending upon the slope of the channel/water course to reach constant measurements in a channel flow under steady state condition. If the flow in channel is fluctuating, it will affect the measurements at the head of the section earlier than the downstream measurement.

According to Sarki et al (2008), the loss can be represented as a rate of decrease inflow rate per unit length of channel as follows:

$$Q_L = \frac{Q_1 - Q_2}{L}. \quad ..3$$

Where: Q_L is the loss rate Lps/100 meter length; Q_1 is the Flow rate in the upstream device (Lps); Q_2 is the Flow rate in the downstream device (Lps); and L is the Length of the channel between the measurements 100 m.

II. MATERIALS AND METHODS

2.1 Site Location and Selection

This study was carried out at the research farm of the Department of Agricultural Engineering at the permanent campus of the University of Uyo. The farm is cultivated majorly by students and villagers of the host community.

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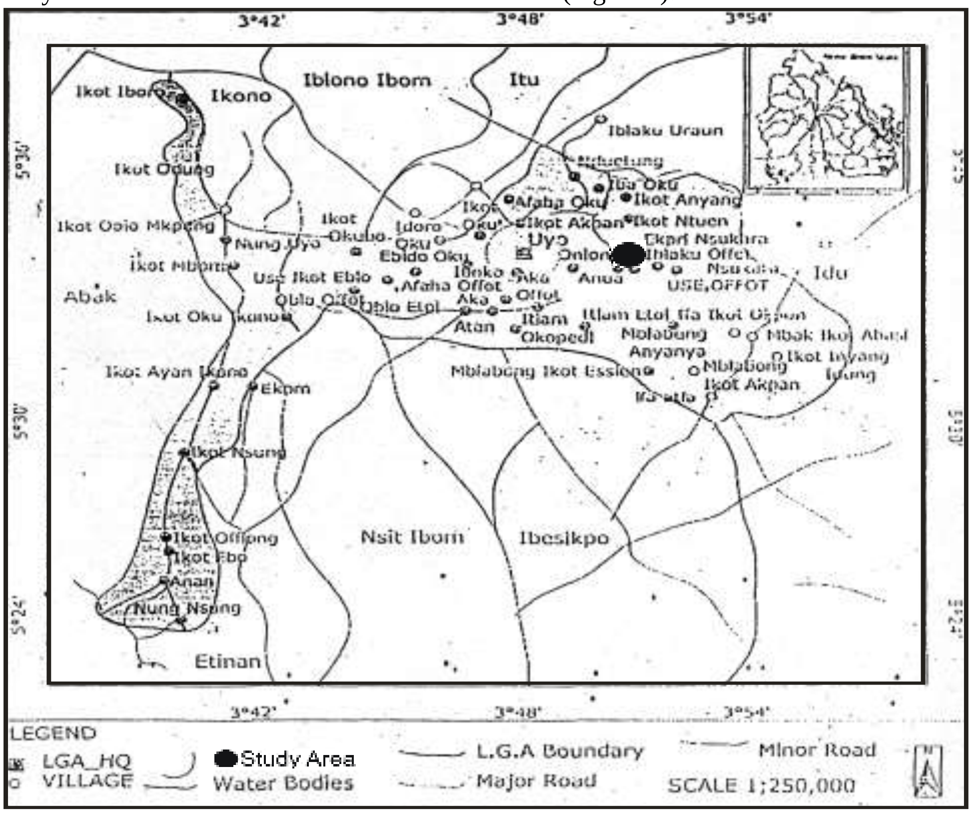
Vegetable (Fluted pumpkin), melon, cassava and maize are the major crops grown on the farm. The farm is located at Nsukara Offot in Uyo Local Government Area of Akwa Ibom State (Figure 1).



Source: Akwa Ibom State Ministry of Lands and Town Planning, Uyo.

Figure 1 Map of Uyo L. G. A. showing study site

Six soil samples were collected from each of the lined and unlined study pits. The undisturbed sampling method with the aid of laboratory auger was used in sample collection. The following parameters of the collected soil samples were determined in the Soil laboratory of the department of Civil Engineering and the Soil science laboratory both of the University of Uyo following the American Society for Testing materials - ASTM standard (2010). They include: Particle size distribution, Texture, Moisture content, hydraulic conductivity, Atterberg parameters (Consistency, liquid limit, plastic limit and plasticity index). Before the construction proper, site cleaning, mapping/pegging exercises was undertaken. The canal was designed and constructed in line with Al-Husseini (2009) approach. Designing unlined channels depend on the conditions, particularly the soil formations, sediment transport characteristics, operational needs and desired standards of maintenance. The canal was of a rectangular cross-section with negligible bed side slope so that the seepage losses at any instance along the length of the canal could be the same. The following essential requirements of a satisfactory type of Channel and Channel lining were considered: Low cost, Impermeability, Hydraulic efficiency (i.e., reduction in rugosity coefficient), Durability, Resistance to erosion, Repair ability, and structural stability.

2.2 Design Parameters

The design of a channel involves the selection of channel alignment, canal length, canal bedwidth, canal depth, freeboard, shapes and size. The length of the canal was 3m, width 1m depth 1m, and the design water level was at 0.6m depth.

2.2.1 Canal Lining Material

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One out of the two constructed canals was lined with a mixture of clay and bentonite in the proportion of 175kg of clay to 2kg of bentonite to ensure proper sealing of the canal reach for optimum seepage control (R. Suresh, 2008). The canal was lined to a depth of 0.6cm. In line with Suresh (2008) and Al-Husseini (2004), the thickness of the liner used was 5cm for the canal walls and 10cm for the canal bed. After the lining exercises, the lined canal was allowed to set for one week before the seepage measurement was taken to ensure more accurate seepage losses.

2.2.2 Seepage Measurement

Seepage measurement was taken in line with the method adopted by Sarki et al, (2008). Two giant drums of water each with storage capacity of $1m^3$ or 1000litres (Gee Pee brand) were placed at the site for storage of water. Ponding method was used to measure the seepage in this method, a designed water volume (900litres) was released gently into the lined and unlined canal (to prevent scouring the canal bed) to the approximate operating depth of 30cm and a periodic record of the drop in water surface with time was taken using a 60cm metre ruler placed to the bed of the canal.

2.2.3 Measurement for Unlined and Lined Canals

A total of 950litres of water each were discharged from the water storage containers into the unlined and lined canals with the help of delivering rubber hose (pipe) from the storage tanks. The actual depth that 900litres of water could have reached in the unlined canal was 300mm. The 50litres deficit observed apparently account for the water (lost to initial seepage) used to cover the bed surface before completion of ponding. The timing commenced immediately the 300mm water depth was observed with the help of the stopwatch in Nokia E5 model cellphone.

III. RESULT AND DISCUSSION

Some engineering properties of the soil were determined prior to the commencement of the canal construction. They include soil moisture content, particle size distribution and soil classification. **Soil Moisture Content**

Moisture content of the soil had values ranging from 8.09% to 8.75%. Soil moisture content was averaged at 8.32% with a mean deviation of 0.372.

Table 1: Particle Size Distribution of the Soil

	Lined Canal			Unlined Canal		
Sample	Sand %	Silt %	Clay %	Sand %	Silt %	Clay %
1	74.20	19.09	14.71	73.84	18.85	15.02
2	73.60	18.72	14.52	74.11	19.13	14.95
3	72.39	10.94	16.63	71.72	10.55	17.23
4	71.82	10.88	16.55	72.43	10.78	16.79
5	77.00	10.98	18.73	76.84	10,71	19.05
6	76.72	10.72	18.48	77.03	10.65	19.14
Mean	74.288	13.555	16.603	74.328	13.992	17.030
Standard Deviation	2.165	4.146	1.787	2.450	4.236	1.742

3.1 Soil Classification

From table 1, the mean percentages of sand, silt, clay and organic matter from the analyzed soil samples were 74.288%, 13.555% and 16.603% for lined canal and 74.328%, 13.992% and 1.030 for the unlined canal respectively. These mean values of the soil particle sizes were used in the reading of the textural class of the soil samples from the Soil textural triangle which shows that it falls into the sandy loam classification

3.1.1 Soil Hydraulic Conductivity

Observations and calculations for hydraulic conductivity (k) of the soil sample are as presented in Table 2.

Table 2: Hydraulic conductivity of the soil

S/N	Initial water reading	Final water reading	Volume of water	Time interval	Q = V/T (mL/sec)	$K = \frac{L}{HA} \times \frac{V}{T}$

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	(mL)	(mL)	V(mL)	t (sec)		(cm/sec)
1	0	450	450	441	1.02	0.0033
2	0	440	440	453	0.97	0.0031
3	0	445	445	452	0.98	0.0032
		Average value				0.0032

Where L is the soil barrel length = 12.5cm.
H is the height or vertical distance between the constant water level in the supply tank and the overflow level of the bottom tank = 50cm
A is the cross sectional area of flow within the soil barrel = 79cm^2

3.2 Liner Properties

3.2.1 Natural Moisture Content of Clay

Observations and calculations for determining moisture content (W) by oven drying method is as shown in Table 3

3.2.3 Hydraulic Conductivity of Liner

Observations and calculations for hydraulic conductivity (k) of the liner (clay) by constant head permeameter method is as shown below in Table 4

Table 3 Natural Moisture content of liner

Sample No.	Mass of container with lid M_1 (g)	Mass of container with lid + wet soil M_2 (g)	Mass of container with lid + dry soil M_3 (g)	$W_n = \frac{M_2-M_3}{M_3-M_1}$	W_n (%)
1	23.23	35.80	32.40	0.3708	37.08
2	22.20	33.40	31.50	0.2043	20.43
3	21.67	33.60	32.50	0.0922	9.22

Average Natural Moisture Content of Clay = 22%

Table 4: Hydraulic conductivity of the liner

S/N	Initial water reading (mL)	Final water reading (mL)	Volume of water V(mL)	Time interval t (sec)	Q = V/T (mL/sec)	$K = \frac{L}{HA} \times \frac{V}{T}$ (cm/sec)
1	0	105	105	614	0.171	5.40×10^{-4}
2	0	115	115	626	0.184	5.81×10^{-4}
3	0	125	125	634	0.97	6.23×10^{-4}
		Average value				5.81×10^{-4}

Where L is the soil barrel length = 12.5cm.
H is the height or vertical distance between the constant water level in the supply tank and the overflow level of the bottom tank = 50cm
A is the cross sectional area of flow within the soil barrel = 79cm^2

3.2.4 Liquid and Plastic Limits of Liner

Observations and calculations for the determination of the plastic and liquid limits of the liner are presented in Tables 5 and 6 respectively. The average of the moisture contents in each case indicates the limits.

Table 5: Computation of Plastic Limit of Clay

Sample	Weight of wet clay m_o (g)	Weight of dry clay (after drying) m_d (g)	$PL = \frac{m_o - m_d}{m_d} \times 100$ (%)
1	12.70	10.55	20.38
2	10.70	8.85	20.56

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Average value	20.47

Table 6: Computation of Liquid Limit of Clay

Sample No.	No. of blows N	Weight of wet sample M_0 (g)	Weight of dry sample m_d (g)	Moisture content (LL) $\frac{m_0-m_d}{m_0}$ x 100%
1	16	4.85	3.35	44.78
2	18	9.65	6.75	42.96
3	25	11.91	8.90	40.95
4	30	15.96	11.15	42.60
5	34	13.21	10.18	29.76
6	40	15.15	11.75	28.94
		Average value		38.33

From table .6, the moisture contents (on normal scale) were plotted against number of blows (on a logarithmic scale) as shown in Figure 1.

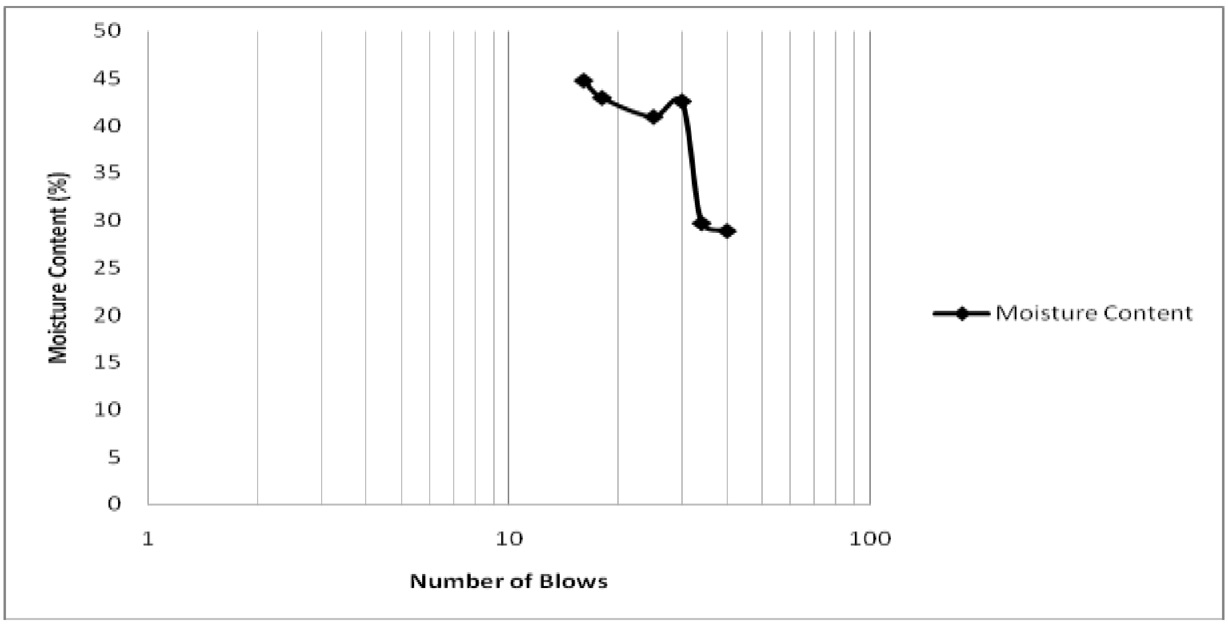

Figure 1: Moisture Content versus Number of Blows

3.3 Seepage Measurement

3.3.1 Seepage in Earth Canal

Observation and measurements obtained from the seepage measurement in the earth canal are presented in Table 7.

Table 7: Computations of seepage in Earth canal

S/N	Time	Cumulative Time	Water level	water loss	volume of loss dd x B x L	Seepage rate	Cumulative Seepage Rate
	(hour)	hour	(m)	m	(m^3)	m^3/hr	m^3/hr

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1	0.167	0.167	0.205	0.055	0.1375	0.825	0.825
2	0.167	0.333	0.164	0.041	0.1025	0.615	1.44
3	0.167	0.500	0.126	0.034	0.085	0.51	1.95
4	0.167	0.667	0.094	0.032	0.08	0.48	2.43
5	0.167	0.833	0.068	0.026	0.065	0.39	2.82
6	0.167	1.000	0.046	0.022	0.055	0.33	3.15
7	0.167	1.167	0.032	0.014	0.035	0.21	3.36
8	0.167	1.333	0.024	0.008	0.02	0.12	3.48
9	0.167	1.500	0.017	0.007	0.0175	0.105	3.585
10	0.167	1.667	0.010	0.006	0.015	0.09	3.675
11	0.167	1.833	0.009	0.001	0.0025	0.015	3.69
12	0.167	2.000	0.008	0.001	0.0025	0.015	3.705
13	0.167	2.167	0.004	0.004	0.01	0.06	3.765
		Total			0.6275	3.765	
		Average Seepage loss per hour				0.29	

Where L = 2.5m and B = 1m

From Table 8, the average seepage loss for the lined canal is 0.29m^3/hour. The cumulative water loss plotted against the cumulative test time is represented in Figure 1.

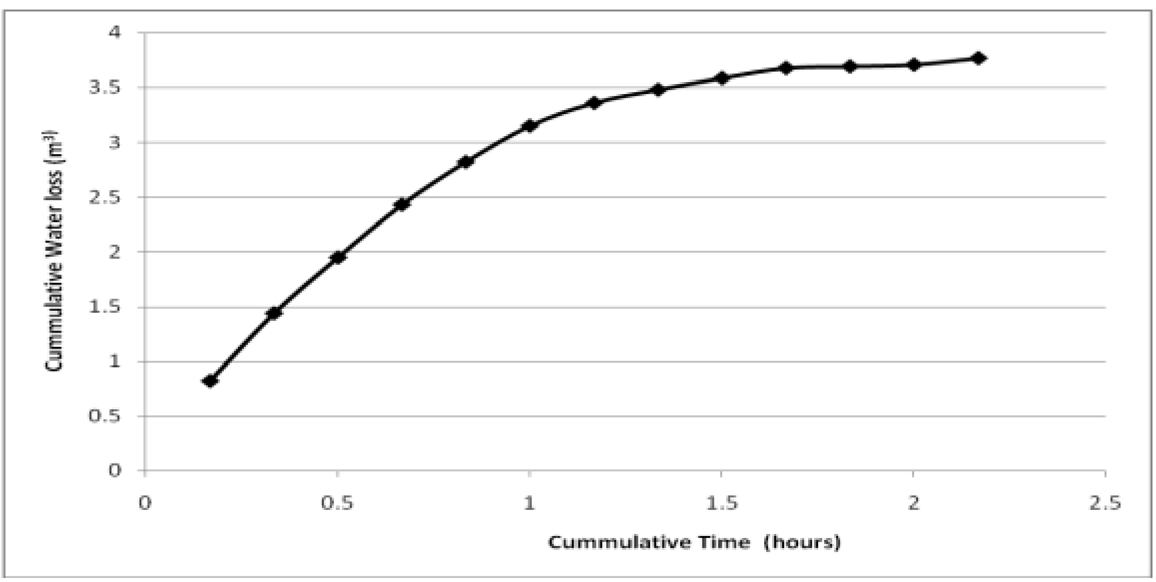

Figure 2 : Seepage rate curve for Earth canal

3.3.2 Seepage in Lined Canal

Using the model(equation) used by Sarki et al (2008), the following observation and measurement were taken.

Table 8: Computations of seepage in Earth canal

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S/N	Time	Cumulative Time	Water level	water loss	volume of loss dd x B x L	Seepage rate	Cumulative Seepage Rate
	(hour)	hour	(m)	m	(m^3)	m^3/hr	m^3/hr
1	1	1	0.251	0.049	0.10584	0.10584	0.10584
2	1	2	0.215	0.036	0.07776	0.07776	0.1836
3	1	3	0.185	0.032	0.06912	0.06912	0.25272
4	1	4	0.154	0.029	0.06264	0.06264	0.31536
5	1	5	0.12	0.034	0.07344	0.07344	0.3888
6	1	6	0.094	0.027	0.05832	0.05832	0.44712
7	1	7	0.065	0.029	0.06264	0.06264	0.50976
8	1	8	0.044	0.022	0.04752	0.04752	0.55728
9	1	9	0.035	0.009	0.01944	0.01944	0.57672
10	1	10	0.027	0.009	0.01944	0.01944	0.59616
11	1	11	0.019	0.008	0.01728	0.01728	0.61344
12	1	12	0.012	0.007	0.01512	0.01512	0.62856
13	1	13	0.005	0.007	0.01512	0.01512	0.64368
		Total			0.64368	0.64368	
		Average seepage loss per hour				0.05	

Where L = 2.4m and B = 0.9m

From Table 8, the average seepage loss per hour for the lined canal is $0.05m^3$/hour withthe cumulative water loss plotted against the cumulative test time is represented in Figure 1.

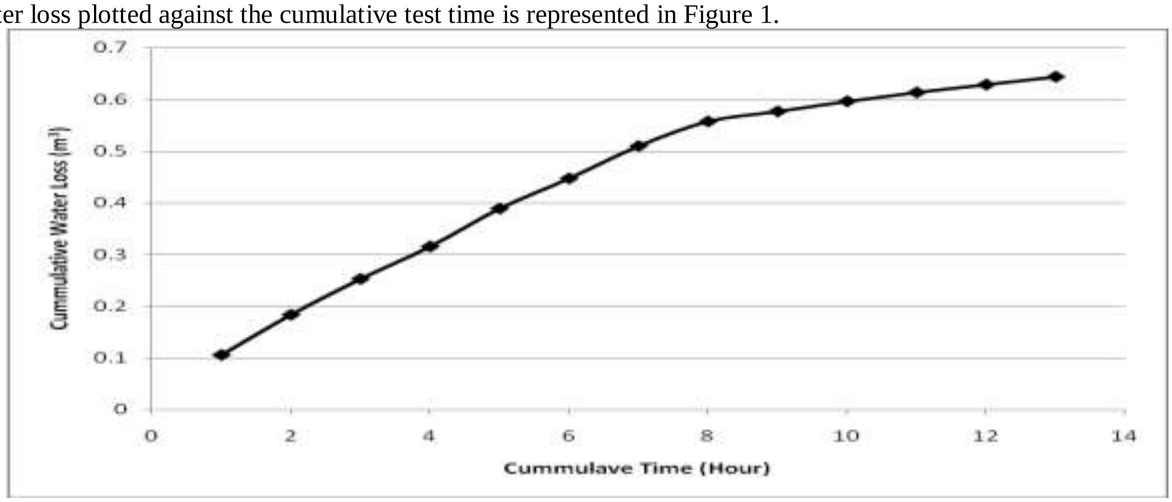

Figure 3 : Seepage rate curve for lined canal

3.3.3 Deviations in Seepage Losses

Comparing the rate of seepage loss between the lined canal and unlined canal, water losses in the unlined canal started just immediately the water was being discharged into the canal. The average seepage loss in the unlined canal ($0.29m^3$/hr) was higher than that of the lined canal ($0.05m^3$/hr). The water lost in the unlined canal was recorded in

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minute where as in the lined canal, the water lost was recorded in hour and the rate of water lost per hour at one section of the canal was the canal was the same throughout the canal cross sector.
There was scouring in the unlined canal while the water was being discharged from the storage drum. Obviously, some water got ponded in the scoured area on the bed of the unlined canal thus making water losses in the said area, difficult to be measured.
However, it is worthy of note that evaporative losses were acknowledged. That is, According to Bouwer (1982), evaporation rate for hot, dry weather being 10mm/day is negligible. This study results are valid for periods of no-rainfall and provided that the soil is not saturated. The results of the study also revealed that seepage loss in earth canal is 82.8% higher than the seepage loss in lined canal. This speaks volume of economic loss where irrigation canals are not lined.
The rate of seepage was observed to decrease with increase in cumulative ponding time that is initial seepage when ponding time was 0.167hr stood at 0.825m^3/hr but decreased to 0.06m^3/hr at 2.167m^3/hr. This agrees with natural phenomenon that the soil was increasing in the rate of saturation. This same result holds for the lined canal but at a lower rate of 0.01512m^3/hr after 13hrs of ponding confirming the effectiveness of lining in reducing and controlling seepage.
soil properties including moisture content, soil particle size distribution and hydraulic conductivity were investigated. Two canals, of dimension 2.5m x 1m x 1m, one of which was lined with mixture of clay and bentonite were constructed. Both canals were ponded with 650Litres of water and allowed for several hours such that the reduced water levels at constant intervals were measured. From the study results, the following conclusions are drawn:

1. Seepage losses in earth canal at Nsukara Offot is 0.29m^3/hour
2. Seepage losses in canal lined with clay and bentonite mixture at Nsukara Offot is 0.05m^3/hour
3. Seepage loss in earth canal is 82.8% higher than seepage loss in lined canal at Nsukara Offot.

IV. CONCLUSION
Based on the results of the study, the mixture of clay and bentonite in the proportion stated in this work is strongly recommended for small and medium scale farmers wishing to control seepage losses. This will help to improve irrigation conveyance efficiency of soils having similar characteristics as contained in this study. The prescription is cheap to put up considering the high cost of high quality liners.

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